JC10 Rec'd PCT/PTO 08 MAR 2002

FORM PTO-1390 (Modified)
(REV 11-2000)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
28944/38284

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
10/070854

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/FR00/02491	08 September 2000	13 September 1999

TITLE OF INVENTION
METHOD FOR JOINT DECODING AND EQUALISING OF A DIGITAL SIGNAL PROTECTED BY A TRELLIS-DEFINED CODE

APPLICANT(S) FOR DO/EO/US
Tortelier, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☐ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

   postcard

JC13 Rec'd PCT/PTO 08 MAR 2002

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/070854	PCT/FR00/02491	28944/38284

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS	PTO USE ONLY
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO	$1040.00		
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO	$890.00		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	$740.00		
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)	$710.00		
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)	$100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =		$890.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		$0.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	2 - 20 =	0	x $18.00	$0.00	
Independent claims	1 - 3 =	0	x $84.00	$0.00	
Multiple Dependent Claims (check if applicable).			☐	$0.00	
TOTAL OF ABOVE CALCULATIONS =				$890.00	
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				$0.00	
SUBTOTAL =				$890.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				$0.00	
TOTAL NATIONAL FEE =				$890.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). ☐				$0.00	
TOTAL FEES ENCLOSED =				$890.00	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of $890.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ______ in the amount of ______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 13-2855 A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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40,091
REGISTRATION NUMBER

March 8, 2002
DATE

PATENT
28944/38284

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: TORTELIER Serial No.: Unassigned Filed: Herewith Title: Method of Decoding and of Joint Equalization of A Digital Signal Protected By A Code Defined By A Trellis Int'l. Application PCT/FR00/02491	I hereby certify that this paper is being Deposited with the United States Postal Service "EXPRESS MAIL POST OFFICE TO ADDRESSEE" service under 37 CFR §1.10 on the date indicated below and is addressed to: Commissioner for Patents, Washington, DC 20231. Richard Zimmermann EXPRESS MAIL mailing label No. **ET924102131US** Date of Deposit: **March 8, 2002**

PRELIMINARY AMENDMENT

Box PCT
Commissioner for Patents
Washington, D.C. 20231

Sir:

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION:

Page 1, between lines 2 and 4, insert the heading
--FIELD OF INVENTION--.

Page 1, between lines 6 and 7, insert the heading
--BACKGROUND OF THE INVENTION--.

Page 2, between lines 35 and 36, insert the heading
--SUMMARY OF THE INVENTION--.

Page 5, line 3, cancel "*It is noteworthy in that,* ".

Page 6, between lines 5 and 6, insert the heading
--BRIEF DESCRIPTION OF THE DRAWINGS--.

Page 9, just before line 1, insert the heading
--MORE DETAILED DESCRIPTION--.

Page 16, lines 18 and 23, replace "δ_m" by "δ_M".

IN THE CLAIMS:

Please amend claims 1 and 2 as follows:

1. (Amended) A method of decoding and of joint equalization of a digital signal protected by a code defined by a trellis, this signal being transmitted on a radio frequency channel according to a transmission with non-interleaved packets, each packet including a known sequence and a sequence of coded data, each sequence of bits $x = \{x_n\}$, from current bit x_n, subjected to the coding process defined by a trellis and to a modulation process, having a corresponding sequence of symbols $y = \{y_n\}$, from current symbol y_n, satisfying the relationship $y_n = f(x_n; x_{n-1}; ...; x_{n-K})$, the sequence of bits prior to the current bit $e_{n-1}(x) = \{x_{n-1}; x_{n-2}; ...; x_{n-K}\}$ representing the state of the coding process at the previous state n-1 and the current symbol y_n of the sequence of symbols satisfies the relationship $y_n = f(x_n, e_{n-1}(x))$, the sequence of symbols being submitted to a transverse filtering with finite impulse response, with filtering coefficients $\{h_0; h_1; ...; h_L\}$ representative of the radio frequency channel in order to generate a sequence of observed symbols $r = \{r_n\}$, each observed symbol r_n satisfying the relationship $r_n = z_n+b_n$ where z_n designates a current symbol at the output of the channel and b_n a residual noise affecting the *channel*, each current symbol at the output of the channel z_n satisfying the relationship:

$$\begin{aligned} z_n &= g\,(y_n;\ y_{n-1};\ldots;\ y_{n-L}) \\ &= h_0 y_n + h_1 y_{n-1} + \ldots + h_L y_{n-L} \\ &= \Phi(x_n;\ x_{n-1};\ \ldots;x_{n-L-K}) \end{aligned}$$

this method consisting in estimating each current bit x_n of the sequence of bits $x = \{x_n\}$ in the sense of the maximum likelihood by minimizing the quadratic error between observed symbol and current symbol at the channel output,

$$\varepsilon^2(x) = \sum_n \left|r_n - z_n\right|^2 = \sum_n \left|r_n - \phi(x_n; x_{n-1};\ldots;x_{n-L-K})\right|^2,$$

wherein, for any current symbol at the output of the channel z_n arising from the transmission, because of multiple paths, the successive sequence of the symbols $\{y_{n-L};\ y_{n-L+1};\ y_{n-1};\ y_n\}$ arising from the coding process for the sequence of bits $x = \{x_n\}$ corresponding to successive states $e_{n-L}(x);\ e_{n-L+1}(x); \ldots; e_{n-1}(x)$ and finally $e_n(x)$, corresponding to branches between successive state nodes of the trellis of the code, this method moreover consisting:

- in calculating said quadratic error on the basis of the set of observed symbols and of the successive state branches of the coding process, on the basis of the branch metric of the last transition $e_{n-1}(x) \rightarrow e_n(x)$ of the coding process, according to the relationship:

$$\varepsilon^2(x) = \sum_n \left|r_n - \left\{\sum_{k\geq 0} h_k y_{n-k}\right\}\right|^2 = \sum_n \left|r_n - h_0 y_n - \left\{\sum_{k\geq 1} h_k y_{n-k}\right\}\right|^2$$

said branch metric being calculated by ascending the successive states at the level of each state node over a length equal to the memory of the channel;

- in inhibiting, in the course of this ascent, the process of error propagation because of the calculation of the branch metrics, by memory-storage at the level of each node i and at each instant of a number $S > 1$ of survivors, each survivor being defined by an accumulated metric M(i,t,k) for the node i at the instant t for the survivor of ranking k in question, $k \in [0, \ldots, S-1]$, and by an updating of each survivor at the instant $t + 1$ for each node by calculation of a branch metric and selection of the S best branch metrics from among the set of possible branch metrics at the node in question;

- in determining the final survivor with the smallest metric, $M_m(0,\tau,1)$, and in reading the corresponding sequence of information bits, by ascending successive state nodes.

2. (Amended) The method according to Claim 1, *wherein* it further consists:

- in determining a next-final survivor with metric $M_{m'}(0,\tau,1)$, adjacent to and immediately above the smallest metric,
- in calculating a metric offset, the absolute value in the difference in metrics between the smallest metric and the immediately higher adjacent metric, $\delta_M = |M_m - M_{m'}|$;
- in comparing this metric offset with a threshold value $\delta_M \leq S_e$, this threshold value S_e being defined on the basis of experimental results and of conditions of use;
- in rejecting the final survivor when said metric offset satisfies the comparison of being below this threshold value, which makes it possible to enhance the reliability of the method.

REMARKS

The above-referenced amendments are entered to place the application into better condition with the U. S. practice. A prompt review of the pending claims, and issuance of a notice of allowance is respectfully requested.

Respectfully submitted,

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March 8, 2002

MARKED-UP VERSION WITH CHANGES MADE

Claims 1 and 2 have been amended as follows:

1. (Amended) A method of decoding and of joint equalization of a digital signal protected by a code defined by a trellis, this signal being transmitted on a radio frequency channel according to a transmission with non-interleaved packets, each packet including a known sequence and a sequence of coded data, each sequence of bits $x = \{x_n\}$, from current bit x_n, subjected to the coding process defined by a trellis and to a modulation process, having a corresponding sequence of symbols $y = \{y_n\}$, from current symbol y_n, satisfying the relationship $y_n = f(x_n; x_{n-1}; ...; x_{n-K})$, the sequence of bits prior to the current bit $e_{n-1}(x) = \{x_{n-1}; x_{n-2}; ...; x_{n-K}\}$ representing the state of the coding process at the previous state n-1 and the current symbol y_n of the sequence of symbols satisfies the relationship $y_n = f(x_n, e_{n-1}(x))$, the sequence of symbols being submitted to a transverse filtering with finite impulse response, with filtering coefficients $\{h_0; h_1; ...; h_L\}$ representative of the radio frequency channel in order to generate a sequence of observed symbols $r = \{r_n\}$, each observed symbol r_n satisfying the relationship $r_n = z_n+b_n$ where z_n designates a current symbol at the output of the channel and b_n a residual noise affecting the [latter] <u>channel</u>, each current symbol at the output of the channel z_n satisfying the relationship:

$$\begin{aligned} z_n &= g(y_n; y_{n-1};...; y_{n-L}) \\ &= h_0 y_n + h_1 y_{n-1} + ... + h_L y_{n-L} \\ &= \Phi(x_n; x_{n-1}; ...; x_{n-L-K}) \end{aligned}$$

this method consisting in estimating each current bit x_n of the sequence of bits $x = \{x_n\}$ in the sense of the maximum likelihood by minimizing the quadratic error between observed symbol and current symbol at the channel output,

$$\varepsilon^2(x) = \sum_n |r_n - z_n|^2 = \sum_n |r_n - \phi(x_n; x_{n-1};...; x_{n-L-K})|^2,$$

[characterized in that] <u>wherein</u>, for any current symbol at the output of the channel z_n arising from the transmission, because of multiple paths, the successive sequence of the symbols $\{y_{n-L}; y_{n-L+1}; y_{n-1}; y_n\}$ arising from the coding process for the sequence of bits $x = \{x_n\}$ corresponding to successive states $e_{n-L}(x)$; $e_{n-L+1}(x)$; ...; $e_{n-1}(x)$ and finally $e_n(x)$,

corresponding to branches between successive state nodes of the trellis of the code, this method moreover consisting:

- in calculating said quadratic error on the basis of the set of observed symbols and of the successive state branches of the coding process, on the basis of the branch metric of the last transition $e_{n-1}(x) \rightarrow e_n(x)$ of the coding process, according to the relationship:

$$\varepsilon^2(x) = \sum_n \left| r_n - \left\{ \sum_{k \geq 0} h_k y_{n-k} \right\} \right|^2 = \sum_n \left| r_n - h_0 y_n - \left\{ \sum_{k \geq 1} h_k y_{n-k} \right\} \right|^2$$

said branch metric being calculated by ascending the successive states at the level of each state node over a length equal to the memory of the channel;

- in inhibiting, in the course of this ascent, the process of error propagation because of the calculation of the branch metrics, by memory-storage at the level of each node i and at each instant of a number $S > 1$ of survivors, each survivor being defined by an accumulated metric M(i,t,k) for the node i at the instant t for the survivor of ranking k in question, $k \in [0, ..., S-1]$, and by an updating of each survivor at the instant $t + 1$ for each node by calculation of a branch metric and selection of the S best branch metrics from among the set of possible branch metrics at the node in question;

- in determining the final survivor with the smallest metric, [$M_m(0,\tau,1)$] $\underline{M_m(0,\tau,1)}$, and in reading the corresponding sequence of information bits, by ascending successive state nodes.

2. (Amended) The method according to Claim 1, [characterized in that] wherein it further consists:

- in determining a next-final survivor with metric $M_{m'}(0,\tau,1)$, adjacent to and immediately above the smallest metric,

- in calculating a metric offset, the absolute value in the difference in metrics between the smallest metric and the immediately higher adjacent metric, $\delta_M = |M_m - M_{m'}|$;

- in comparing this metric offset with a threshold value $\delta_M \leq S_e$, this threshold value S_e being defined on the basis of experimental results and of conditions of use;

- in rejecting the final survivor when said metric offset satisfies the comparison of being below this threshold value, which makes it possible to enhance the reliability of the method.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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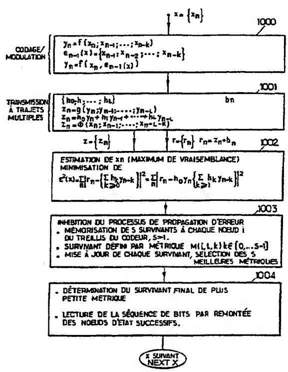
[continued on next page]

As printed

(54) Title: METHOD FOR JOINT DECODING AND EQUALISING OF A DIGITAL SIGNAL PROTECTED BY A TRELLIS-DEFINED CODE

(54) Titre: PROCEDE DE DECODAGE ET D'EGALISATION CONJOINTE D'UN SIGNAL NUMERIQUE PROTEGE PAR UN CODE DEFINI PAR UN TREILLIS



1000...CODING/MODULATION
1001...MULTIPATH TRANSMISSION
1002...ESTIMATING xn (MAXIMUM LIKELIHOOD) MINIMISING...
1003...INHIBITION OF ERROR PROPAGATING PROCESS...STORING S SURVIVORS AT EACH NODE i OF THE ENCODING TRELLIS, S > 1...SURVIVOR DEFINED BY METRIC...UPDATING EACH SURVIVOR. SELECTING S BEST METRICS
1004...DETERMINING THE FINAL SURVIVOR OF THE LEAST METRIC...READING THE BIT SEQUENCE BY BACKTRACKING THROUGH SUCCESSIVE STATE NODES

(57) Abstract: The invention concerns a method for jointly decoding and equalising a digital signal protected by a trellis-defined code and transmitted through a channel. The method consists in carrying out a maximum likelihood estimate of each current bit x_n by minimising the quadratic error between the observed symbol V_n and the current symbol in the channel output z_n, the quadratic error being calculated (1002) from the set of observed symbols based on the branch metric of the last transition $e_{n1}(x) \rightarrow e_n(x)$ according to the relationship (I); wherein k represents the rank of the coefficients of transverse filtering introduced by the radioelectric channel. The branch metric is calculated by backtracking through the successive states and the error propagating process is inhibited (1003) while backtracking through the successive states by storing at each node S survivors and by updating each survivor at the next time. The final survivor of the least metric is determined (1004) and the sequence of bits is read by backtracking through the successive nodes. The invention is applicable to ATM radio transmission.

(57) Abrégé: L'invention concerne un procédé de décodage et d'égalisation conjointe d'un signal numérique protégé par un code défini par un treillis et transmis par un canal. Le procédé consiste à estimer chaque bit courant x_n au sens du maximum de vraisemblance par minimisation de l'erreur quadratique entre symbole observé V_n et symbole courant en sortie du canal z_n, l'erreur quadratique étant calculée (1002) à partir de l'ensemble des symboles observés en fonction de la métrique de branche de la dernière transition $e_{n-1}(x) \rightarrow e_n(x)$ selon la relation (I), K désignant le rang des coefficients du filtrage transverse introduit par le canal radioélectrique. La métrique de branche est calculée par remontée des états successifs

[continued on next page]

WO 01/20861 A1

Method of decoding and of joint equalization of a digital signal protected by a code defined by a trellis

The invention relates to a method of decoding and of joint equalization of a digital signal protected by a code defined by a trellis.

With the recent advent and development of the exchange of information by way of digital messages, reliable and high-performance transmission of digital data has become the economic stake.

Among the transmission modes used, digital packet transmission occupies a pre-eminent place, by reason of the flexibility and of the reliability of the protocols for transmission of these data.

However, the development of transmissions at very high throughput on radio frequency channels, featuring characteristics of frequency selectivity which are variable over time, makes it necessary to submit the digital data constituting these messages and the medium for this information, to a process of protection by specific coding. These protection processes are for the purpose of introducing into the digital data a certain amount of redundancy, which, in the presence of degradation of these data due to the transmission, makes it possible, under certain conditions, to reconstitute the original signal. By way of non-limiting example, mention may be made of the protection of digital data by a convolutional code of efficiency R = k/n where the efficiency k/n is representative of the redundancy introduced, and the ATM (Asynchronous Transmission Mode) transmission on a radio link, with granularity at the level of the ATM cells. It will be recalled that the notion of granularity implies the possibility of transmission of each ATM cell in isolation, without interlacing of the cells.

By reason of the physical nature of the radio frequency channel, the transmission of digital data takes place in the presence of multiple propagation

paths. The reception and the decoding of these messages consequently require equalization of the received signal. The complexity of the equalization processing operations increases very rapidly with the dispersion in the delays, and, likewise, with the throughput of the symbols transmitted. This is particularly the case in the urban environment, upon transmission of mobile-telephony messages and signals.

The protection introduced by coding of these digital data transmitted makes it possible partially to remedy the errors introduced. However, the equalization made necessary by interference on the symbols, due to the multiple paths, is never perfect and it is then necessary, as far as possible, to disperse the error bursts at the output of the equalizer, so that the channel decoder can function on a signal with a substantially constant, further reduced error density.

Such a method of operating can be obtained by a process of interlacing of the coded data, which prevents the notion of granularity, and which, moreover, introduces a delay which it is necessarily sought to minimize, which, a priori, appears contradictory.

Furthermore, for high throughput, the size of the interlacing becomes prohibitive.

Moreover, the presence of a channel decoder downstream of the equalization device, the equalizing/decoding sequencing being made necessary by the coding/transmission/multiple-path sequencing on transmission, encourages the use of an equalization process giving flexible equalized symbols, that is to say symbols the firm value of which is accompanied by a likelihood probability value, which further increases the complexity of the equalization and of the overall processing.

The object of the present invention is to remedy the drawbacks of the methods of the prior art set out above.

One object of the present invention, consequently, is the implementation of a method making it possible jointly to carry out the operations of equalization and of channel decoding directly on the trellis of the channel decoder, a trellis the complexity of which is fixed and independent of the length of the pulse response of the channel.

Another object of the present invention is the implementation of a method making it possible jointly to carry out the operations of equalization and of channel decoding for digital data transmitted in packet form, the pulse response of the channel being assumed to be constant during the transmission of a packet.

Another object of the present invention is the implementation of a method making it possible jointly to carry out the operations of equalization and of channel decoding for digital data transmitted in packets, in the absence of interlacing over several packets, this operating mode being particularly suitable for high-throughput transmission systems which have to provide granularity at the packet level, such as the ATM systems on a radio link.

Another object of the present invention is the implementation of a method making it possible jointly to carry out the operations of equalization and of channel decoding, dispensing with the necessity for flexible output equalization, because of the joint nature of the equalization and channel-decoding operations.

Another object of the present invention is the implementation of a method making it possible jointly to carry out the operations of equalization and of channel decoding particularly adapted to the processing of a modulation with a large number of states, which makes it possible to get round the significant increase in the complexity of a process in the sense of the maximum likelihood of conventional type.

Another object of the present invention is, finally, the implementation of a method making it

possible jointly to carry out the operations of equalization and of channel decoding, making it possible to avoid the phenomenon of error propagation during the decoding, by implementing an adapted version of the Viterbi algorithm.

The method of joint decoding and of equalization of a digital signal protected by a code defined by a trellis, which is the subject of the present invention, applies to a signal transmitted with non-interleaved packets. Each packet includes a known sequence and a sequence of coded data, each sequence of bits $x = \{x_n\}$, from current bit x_n, subjected to the coding process defined by a trellis and to a modulation process, having a corresponding sequence of symbols $y = \{y_n\}$, from current symbol y_n, satisfying the relationship $y_n = f(x_n; x_{n-1}; \ldots; x_{n-K})$. The sequence of bits prior to the current bit, $e_{n-1}(x) = \{x_{n-1}; x_{n-2}; \ldots; x_{n-K}\}$ represents the state of the coding process at the previous state n-1 and the current symbol y_n of the sequence of symbols satisfies the relationship $y_n = f(x_n, e_{n-1}(x))$. This sequence of symbols is in fact submitted to a transverse filtering with finite impulse response, with filtering coefficients $\{h_0; h_1; \ldots; h_L\}$ representative of the radio frequency channel in order to generate a sequence of observed symbols $r = \{r_n\}$. Each observed symbol r_n satisfies the relationship $r_n = z_n+b_n$ where z_n designates a current symbol at the output of the channel and b_n a residual noise affecting the channel. Each current symbol at the output of the current channel z_n satisfies the relationship:

$$\begin{aligned} z_n &= g(y_n; y_{n-1}; \ldots; y_{n-L}) \\ &= h_0 y_n + h_1 y_{n-1} + \ldots + h_L y_{n-L} \\ &= \Phi(x_n; x_{n-1}; \ldots; x_{n-L-K}). \end{aligned}$$

This method consists in estimating each current bit x_n of the sequence of bits $x = \{x_n\}$ in the sense of the maximum likelihood by minimizing the quadratic error between observed symbol and current symbol at the channel output

$$\varepsilon^2(x) = \sum_n |r_n - z_n|^2 = \sum_n |r_n - \phi(x_n; x_{n-1}; ...; x_{n-L-K})|^2,$$

It is noteworthy in that, for any current symbol at the output of the channel z_n arising from the transmission, because of multiple paths, the successive sequence of the symbols $\{y_{n-L}; y_{n-L+1}; y_{n-1}; y_n\}$ arising from the coding process for the sequence of bits $x = \{x_n\}$ corresponding to successive states $e_{n-L}(x)$; $e_{n-L+1}(x)$; ...; $e_{n-1}(x)$ and finally $e_n(x)$, which define branches between successive state nodes, a succession of branches designating a path of a trellis representing this code, this method consists moreover in calculating the quadratic error on the basis of the set of observed symbols and of the successive state branches of the coding process, on the basis of the branch metric of the last transition $e_{n-1}(x) \rightarrow e_n(x)$ of the coding process, according to the relationship:

$$\varepsilon^2(x) = \sum_n \left| r_n - \left\{ \sum_{k\geq 0} h_k y_{n-k} \right\} \right|^2 = \sum_n \left| r_n - h_0 y_n - \left\{ \sum_{k\geq 1} h_k y_{n-k} \right\} \right|^2$$

This branch metric is calculated by ascending the successive states at the level of each state node over a length equal to the memory of the channel, and in inhibiting, in the course of this ascent the process of error propagation because of the calculation of the branch metrics, by memory-storage at the level of each node i and at each instant of a number S > 1 of survivors, each survivor being defined by an accumulated metric M(i,t,k) for the node i at the instant t for the survivor of ranking k in question, $k \in [1, S]$, and by an updating of each survivor at the instant t + 1 for each node by calculation of a branch metric and selection of the S best branch metrics from among the set of possible branch metrics at the node in question. The final survivor is determined as being the survivor with the smallest metric, $M_m(0,\tau,1)$, and the

corresponding sequence of information bits is read by ascending successive state nodes.

The method, the subject of the present invention, finds an application to any ATM transmission system over a radio link, with granularity.

It will be better understood on reading the description and on perusing the drawings below, in which, in addition to Figure 1 relating to the prior art,

- Figure 2a represents a block diagram of a coding and transmission process making it possible to define the context of implementation of the method for joint decoding and equalization of a digital signal protected by a code defined by a trellis, in accordance with the subject of the present invention;

- Figure 2b represents, by way of illustrative example, a flow chart representative of the method of joint coding and equalization of a digital signal protected by a code defined by a trellis, in accordance with the subject of the present invention;

- Figure 3a represents, by way of illustration, a path of the coder trellis, in solid line, and the sequence of symbols z_n corresponding to this path;

- Figures 3b and 3c represent an illustrative diagram of calculation of the S best metrics at each node of the trellis represented in Figure 3a;

- Figure 4 represents a flow chart of a variant implementation of the method which is the subject of the invention as represented in Figure 2b;

- Figure 5a represents a block diagram of an operating mode used to carry out trials on simulation of implementation of the method which is the subject of the present invention;

-Figures 5b and 5c represents various comparative tests of values of packet-error rates obtained by virtue of the implementation of the method which is the subject of the present invention and to an optimal solution by decoding then equalization.

Prior to the description proper of the method of joint decoding and of equalization of a digital signal protected by a code defined by a trellis, the subject of the present invention, reminders relating to the state of the art and to the current state of knowledge will be given below.

The systems for transmission of information, such as the recent mobile-radio systems with time-division multiple access, transmit their data in the form of packets of bits coded in advance. Within these packets of bits is inserted a sequence, known as training sequence, which makes it possible to obtain a good estimate of the channel, including the transmission and reception filters. The shape of the packets which are adopted in the context of the illustration of the implementation of the method, the subject of the present invention, is given below by reference to Figure 1 relating to the prior art. The sequences of bits constituting training sequences may, for example, be Cazac sequences chosen for their auto-correlation properties.

The transmission channel thus introduces distortions on reception, these distortions being called inter-symbol interference. In the known solutions of the prior art, it is necessary to employ an equalizer so as to reduce or attempt to suppress the above-mentioned distortions. The functions of equalization and of decoding are separated in the above-mentioned devices of the prior art.

The context of generation of sequences of bits within the framework of the transmission process of the above-mentioned mobile-radio systems is illustrated now in connection with Figure 2a.

In a general way, it is indicated that the method, the subject of the present invention, applies to a digital signal as represented in Figure 1, this digital signal being protected by a code defined by a trellis. It will be recalled, thus, that the notion of code defined by a trellis covers the methods of

convolutional coding, coding of TCM type, and block coding, for example, in a non-limiting way.

More specifically, the signal is transmitted on the radio frequency channel according to a transmission with non-interleaved packets, each of the packets corresponding to the data structure as represented in Figure 1.

By reference to Figure 2a, it is indicated that each sequence of bits $x = \{x_n\}$, from current bit x_n, is thus subjected to the coding process defined by a trellis and to a modulation process to which corresponds a sequence of symbols $y = \{y_n\}$, the current symbol being designated by y_n. Hence, each current symbol satisfies the relationship:

$$y_n = f(x_n;\ x_{n-1};\ \ldots;\ x_{n-K}).$$

In the foregoing relationship, it is indicated that f designates a coding function of depth K taking account of the modulation process.

The sequence of bits prior to the current bit x_n, a sequence of bits designated by $e_{n-1}(x)$, satisfies the relationship:

$$e_{n-1}(x) = \{x_{n-1};\ x_{n-2};\ \ldots;\ x_{n-K}\}$$

and represents the state of the coding process at the previous state n-1. The current symbol y_n of the sequence of symbols then satisfies relationship (1):

$$y_n = f(x_{n,}\ e_{n-1}(x)) \qquad (1)$$

By reason of the presence of a multipath transmission channel, the sequence of symbols y is in fact subjected to a process equivalent to a transverse filtering with finite impulse response for which the filtering coefficients can be defined by $\{h_0;\ h_1;\ \ldots;\ h_L\}$. These filtering coefficients are representative of the radio frequency transmission channel.

As represented in Figure 2a, the succession of the operation of coding/modulation then of transmission via the multipath channel makes it possible to generate a sequence of observed symbols denoted $r = \{r_n\}$, each observed symbol in fact corresponding to a current symbol at the channel output, denoted z_n, to which a

residual noise b_n is added, this residual noise affecting each of the current symbols at the above-mentioned channel output. The residual noise is centered Gaussian white noise.

Thus, each observed symbol r_n satisfies the relationship:

$$R_n = z_n + b_n$$

Each current symbol at the channel output satisfies relationship (2):

$$\begin{aligned} z_n &= g\ (y_n;\ y_{n-1};\ldots;\ y_{n-L}) \\ &= h_0 y_n + h_1 y_{n-1} + \ldots + h_L y_{n-L} \qquad (2) \\ &= \Phi(x_n;\ x_{n-1};\ \ldots;\ x_{n-L-K}). \end{aligned}$$

According to one noteworthy aspect of the method, the subject of the present invention, by reference to Figure 2a, it is indicated that the process of coding/modulation and the process of transmission via the multipath channel are likened to a cascading of an external code and of an internal code, the internal-code function being fulfilled by the multipath transmission channel. Thus, the internal and external codes consist respectively of a memory device which it is possible to represent by a trellis. To the combination of channel coder + transmission channel, there corresponds a "global" trellis, called super-trellis, the number of states of which is equal to the product of the number of states of the two individual trellises, that is to say a number of states equal to 2^{L+K} for BPSK modulation and an efficiency code 1/n. The method which is the subject of the present invention is noteworthy in that it uses only the trellis of the channel coder, the number of states of which is independent of the number of states of the modulation and of the length L of the channel.

Although the complexity of the trellis of the internal code, that is to say of the trellis generated by the multipath channel, grows exponentially with the number of states of the modulation and the length of the channel in terms of symbol time, the simple decoding of the super-trellis thus constituted is made

prohibitive in terms of complexity for transmissions at high throughput.

In the simplest solutions, the reduction of the super-trellis is brought down to only the external coding trellis, the branch metric then being calculated in the manner of a DFSE process, standing for Decision Feedback Sequence Estimation, by ascending nodes of the trellis thus simplified. However, such a process does not appear to be sufficiently effective since it presents the drawback of an error-propagation phenomenon upon ascending successive nodes, errors inherent in the above-mentioned DFSE process.

The object of the method, the subject of the present invention, is to remedy the drawbacks of the above-mentioned prior art by the determination of the optimal reception on the basis of the super-trellis and by the implementation of a generalized Viterbi decoding technique, more widely designated by GVA decoding, standing for Generalized Viterbi Algorithm.

For a more detailed description of this GVA decoding process, reference may usefully be made to the article published by T. HASHIMOTO, entitled A List-Type Reduced-Constraint Generalization of the Viterbi Algorithm, IEEE Transactions on Information Theory, Vol. IT-33, No. 6, Nov. 1987.

Thus, in accordance with one particularly noteworthy aspect of the method, the subject of the present invention, it consists in estimating each current bit x_n of the sequence of bits $x = \{x_n\}$ in the sense of the maximum likelihood by minimizing the quadratic error between observed symbol and current symbol at the output of the channel z_n.

In Figure 2b, in order to enhance the understanding of the implementation of the method, the subject of the present invention, the coding stage has been represented at stage 1000 on the basis of the sequence of bits x, followed by a stage 1001 corresponding to the multipath transmission so as to generate the sequence of observed symbols $r = \{r_n\}$ and

the series of current symbols at the output of the channel $z = \{z_n\}$.

Stage 1001 is then followed by a stage 1002 making it possible to initiate the estimating of x_n by minimizing the quadratic error satisfying the relationship:

$$\varepsilon^2(x) = \sum_n |r_n - z_n|^2 = \sum_n |r_n - \phi(x_n; x_{n-1}; \ldots; x_{n-L-K})|^2 .$$

By reference to Figure 3a, it is indicated that, for any current symbol at the output of the channel z_n arising from the multipath transmission, the successive sequence of symbols y_{n-L}; y_{n-L+1}; y_{n-1}; y_n being emitted by the coding process for this above-mentioned sequence of bits, the process of coding/modulation and of transmission corresponds to successive states $e_{n-L(x)}$; $e_{n-L+1(x)}$; ...; $e_{n-1(x)}$ and finally $e_{n(x)}$, these successive states corresponding to branches between successive state nodes as represented in the above-mentioned Figure 3a.

The estimating of the successive bits x_n in the sense of the maximum likelihood, corresponding to the method which is the subject of the present invention, then leads to seeking the sequence of bits $\{x_n\}$ which minimizes the previously expressed quadratic error.

In accordance with the method, the subject of the present invention, this quadratic error can be expressed by taking account of the preceding relationships in the form of the relationship (3):

$$\begin{aligned} \varepsilon^2(x) &= \sum_n |r_n - g(y_n; y_{n-1}, \ldots, y_{n-L})|^2 \\ &= \sum_n \left| r_n - \left\{ \sum_k h_k y_{n-k} \right\} \right|^2 \end{aligned} \qquad (3)$$

With $y_n = f(x_n; e_{n-1}(x))$.

In the foregoing relationship (3), the term $r_n - \left\{ \sum_k h_k y_{n-k} \right\}$ can be put in the form:

$$r_n - \{h_0 f(x_n; e_{n-1}(x)) + h_1 f(x_{n-1}; e_{n-2}(x)) + \ldots + h_L f(x_{n-L}; e_{n-L}(x))\}.$$

The term between brackets of the preceding relationship corresponds to the response of the transverse filter representative of the multipath transmission channel subjected to the sequence of symbols following on from the process of coding/modulation over a length L corresponding to the memory of the channel, this sequence of symbols being written y_{n-L}, y_{n-L+1}, y_{n-1}, y_n. This sequence is sent out by the coder with t = n under the assumption of a sequence of bits $x = \{x_n\}$. Under these conditions, the coder then passes through the states $e_{n-L}(x)$; $e_{n-L+1}(x)$; ...; $e_{n-1}(x)$ so as to arrive finally at the state $e_n(x)$. The current symbol at the output of the channel during the last transition is then equal to $z_n = \sum_k h_k y_{n-k}$.

The relationship (4) below:

$$\left| r_n - \left\{ \sum_{k \geq 0} h_k y_{n-k} \right\} \right|^2 = \left| r_n - h_0 y_n - \left\{ \sum_{k \geq 1} h_k y_{n-k} \right\} \right|^2 \qquad (4)$$

thus defines the branch metric of the last transition $e_{n-1}(x) \rightarrow e_n(x)$ and can be calculated in the manner of the DFSE process by ascending the successive states previously visited. This metric depends on the path followed in the trellis in order to arrive at a given state $e_n(x)$.

This method of calculating the metric intrinsically contains the error-propagation problem mentioned above in the description.

For this reason, and with the aim of making the joint decoding and equalization method, the subject of the present invention, robust and effective, the method furthermore consists, at stage 1003 represented in Figure 2b, in inhibiting, in the course of this ascent, the error-propagation process because of the calculation of the branch metrics, this inhibition being carried out by memory storage, at the level of

each node i and at each instant t, of a number of survivors S greater than 1, each survivor being defined by a metric M(i,t,k) for the node i at the instant t for the survivor of ranking k in question. For S survivors, it is recalled that $k \in [0, S-1]$. An update of each survivor is then carried out at the instant t+1 for each node i by calculation of a branch metric and selection of the S best branch metrics from among the set of the 2S possible branch metrics at the node in question.

The stage 1003 described above is then followed by a stage 1004 consisting in determining the final survivor with the smallest metric Mm $(0,\tau,1)$ and in reading the sequence of corresponding information bits by ascending the state of the successive state nodes.

It will be understood, needless to say, that the method, the subject of the present invention, can then be repeated for any following sequence of bits corresponding to a message transmitted.

A more detailed description of the process of inhibiting the propagation of errors will now be given in connection with Figure 3b.

By reference to the above-mentioned Figure 3b, it is indicated that the error-propagation inhibition process consists in adopting a number S > 1 of survivors in each node of ranking i and at each instant t. This is because, if the true path of the trellis, the one which corresponds to the sequence of symbols sent, is not the best one at a given instant, it should not, however, be lost permanently.

By reference to the above-mentioned figure, it is indicated that the current symbol at the output of the channel $z_n = \sum_k h_k y_{n-k}$ · is obtained under the assumption that the state $e_n(x)$ is reached via the succession of states $e_{n-L}(x)$, $e_{n-L+1}(x)$, ..., $e_{n-1}(x)$ as represented in the drawing.

Under the assumption, by way of non-limiting example, of a trellis arising from a convolutional code

of efficiency 1/n, therefore corresponding to a trellis including $N = 2^K$ states, two branches thus depart from each node, one corresponding to a 0-value bit at the input of the coder, the other to a 1-value bit at this same input of the coder.

At each node of ranking i and at each instant t, S survivors are stored, each survivor corresponding to a sequence of bits, denoted $S_{i,t,k}$ where i designates the ranking of the node in question, t the corresponding instant and k the ranking of the survivor in question such that $0 \leq k \leq S-1$. Each sequence of bits constituting a survivor is characterized by a length, called accumulated metric of paths, denoted M(i,t,k), that is to say metric of the k^{th} survivor at the node of ranking i at the given instant t. It will be recalled that the notion of metric corresponds to the definition according to which, in the theory of measurement in a given space, the notion of metric is based on the formula of the distance between two points of this space.

The metric values M (i,t,k) being known at any instant t, their updating at the instant t+1 can be carried out in the manner below, in the case of a code of efficiency 1/n:

- any node of ranking i is consecutive on two antecedents or ancestors, as represented in Figure 3c, j_1 and j_2, which are determined by their sets of S respective survivors such as $S_{j1,t,k}$ and $S_{j2,t,k}$, with $0 \leq k \leq S-1$ and with respective metrics M (j_1,t,k) and $M(j_2,t,k)$. There therefore exist 2S possible ways of reaching a node of ranking i at the instant t+1 by reason of S possibilities for the ancestor j_1 at the instant t and S possibilities for the ancestor j_2 at this same instant t, each ancestor being of the form of a survivor at the instant t prolonged by a branch going from j_1, j_2 respectively, to the node of ranking i.

For each of these 2 × S candidates, the metric of the last branch, that is to say that incident on the node of ranking i, is calculated according to the

foregoing relationship (4) by ascending the surviving paths in each ancestor j_1 and j_2. The branch metrics thus obtained are denoted $\delta m(j,i,k)$ and thus the following quantities are obtained:

$$M(j_1, t, k) + \delta m\ (j_1, i, k)$$
for $k = 0, \ldots, S-1$
$$M(j_2, t, k) + \delta m\ (j_2, i, k)$$
with $k = 0, \ldots, S-1$.

It is thus possible, for the node of ranking i at the instant t+1, to adopt the S best paths from among the 2 × S possible, which makes it possible to obtain S survivors for the node of ranking i at the instant t+1.

As regards the implementation of stage 1004, it is indicated that this can be carried out when all the coded symbols of a packet have been received and when the preceding operations have been carried out, it then being possible to determine the final survivor of smallest metric. It is a matter, under this assumption, of the implementation of a Viterbi algorithm according to an extended version, and it is then possible to ascend the best path in order to read the corresponding sequence of information bits via an ascending operation, known by the name of Back Tracking. As regards the number of survivors adopted, it is indicated that S can be taken to be equal to 4, in a non-limiting way.

A more detailed description of a specific operating mode making it possible to enhance the reliability of the method, the subject of the present invention, will now be given in connection with Figure 4.

In Figure 4 has been represented the above-mentioned specific operating mode, which can consist, at a stage 2000, in determining the second-best survivor with respect to the survivor of smallest metric, the metric of this next-final survivor being denoted $M_{m'}(0,\tau,1)$, this metric being adjacent to and

immediately above the smallest metric mentioned above in the description.

Stage 2000 can then be followed by a stage 2001 consisting in calculating a metric offset, the absolute value in the difference in metrics between the smallest metric and the immediately higher adjacent metric, this metric offset satisfying the relationship:

$$\delta_M = |M_m - M_{m'}|$$

By way of simplification, the metrics have been designated by M_m for the smallest metric and $M_{m'}$ for the adjacent metric immediately above the smallest metric.

The metric offset is then compared, at a test stage 2002, with a threshold value according to the relationship:

$$\delta_M \leq S_e$$

the value of S_e possibly being defined on the basis of experimental results and of conditions of use.

If δ_m is below the threshold 2002, the best two survivors are too close and choosing between the two is not reliable. The packet is declared to be erased, 2004, since the two decodings on the two paths would have led to different results.

In the opposite case, δ_m > threshold, the decoding is assumed to be correct and the packet is accepted, 2003.

Simulations have been carried out in order to reveal the performance of the method, the subject of the present invention, described above.

In Figure 5a has been represented the corresponding operating modes in the context of a block diagram for the channel part on the basis of a binary code A_1, of a coder introducing a convolutional coding A_2, of a channel modulation of MDP4 type, A_3, of a known-sequence insertion of CAZAC type, A_4, and of a Nyquist-root filtering A_5.

As regards the transmission by the multipath radio frequency channel, the latter corresponded to a mobile radio channel B_1 followed by the addition of Additive White Gaussian Noise B_2.

As regards the reception part, this corresponded to Nyquist-root filtering C_1, followed by channel estimation C_2 then joint equalization and coding, in accordance with the method which is the subject of the present invention, C_3, and a decision C_4.

The simulation tests were carried out by virtue of the COSSAP software, marketed by the company SYNOPSYS. The roll-of factor of the Nyquist-root filtering was set at 0.25 and the convolutional code used was a code with constraint-length code of 5, i.e. a trellis of 16 states. The generator polynomials were of the form:

$$G_1(D) = 1+D^3+D^4$$

and

$$G_2(D) = 1+D+D^3+D^4$$

introducing a minimum distance of 7. The modulation chosen at the output from the convolutional code was phase modulation with four states turned by 45° so as to use the CAZAC sequences.

Figure 5b represents the results of tests with a fixed radio frequency channel, that is to say a channel including filtering coefficients h_0, h_1, h_2 and h_3 of fixed value. These coefficients had the values given below in table 1:

TABLE 1

h_0	h_1	h_2	h_3
0.38	0.60	0.60	0.38

The results, compared with the optimal solution, are represented in Figure 5b.

In the light of Figure 5b, it may be noted that, although the method, which is the subject of the present invention, is sub-optimal, it nevertheless gives performance close to the optimal solution for a tolerable complexity, that is to say S = 4.

The pure decoding curve, in dots and dashes, corresponds to the performance of the convolutional

code chosen in Gaussian noise. The results obtained are represented in solid line for the implementation of the method, the subject of the present invention. The degradation introduced with respect to the case of the pure decoding seems to be less than the value of 4.2 dB and results from the interaction between the trellis of the channel, internal code, and trellis of the coding, external code. The method, the subject of the present invention, makes it possible to obtain a result close to the optimal solution represented in dots in Figure 5b, the x-axis being graduated in decibels, dB, and the y-axis in bit error rate, BER.

Figures 5c to 5h represent the frame error rate FER on the y-axis, with respect to the level in dB on the x-axis. This is because, for systems of the radio or fixed ATM type, only the cell or frame error rate is relevant.

In Figure 5c has been represented the case of a mobile radio channel of the Typical Urban type of the GSM for a usable throughput at 2 Mbit/s. The coefficients of the filter, which are representative of the radio frequency transmission channel, follow a complex Gaussian distribution, the time-domain variation being given by a normalized Doppler profile. At the throughput of 2 Mbit/s a single radio frequency channel exhibits a great deal of interference between symbols by reason of the high level of the throughput. The channel of Typical Urban type represented in Figure 5c corresponds to a situation of the urban macrocellular type, for which the throughput at 2 Mbit/s corresponds well to the evolution of mobile services towards multimedia. The values of the filtering coefficients are given in table 2 for the corresponding radio frequency channel:

TABLE 2

Coefficient number i	Relative time (µs)	Average power (dB)	Doppler spectrum
1	0.0	-3.0	CLASS
2	0.2	0.0	CLASS
3	0.5	-2.0	CLASS
4	1.6	-6.0	CLASS
5	2.3	-8.0	CLASS
6	5.0	-10.0	CLASS

On inspecting Figure 5c, it will be noted that the choice of S = 4 or S = 8, causes no very significant change in performance. Consequently, it can be concluded that the optimum is substantially achieved for S = 4.

Simulation trials were also carried out in the context of the BRAN project for a usable throughput equal to 25 Mbit/s, the BRAN (Broadband Radio Access Network) project, corresponding to the European project envisaging the normalizing of high-throughput ATM radio networks within interior-type environments. This project brings together five very severe channel models, that is to say very frequency-selective models, model A, B, C, D and E, for which tests were carried out and plotted on Figures 5d to 5h described below. The user throughput of 25 Mbit/s for a 25 MHz band was fixed for an allowable frame-error rate set at 10^{-2}.

The various types of channels corresponding to the above-mentioned model are more or less easy to equalize on the basis of their fading statistics and of their RMS delay. Model D represented in Figure 5g is the only one to contain fading of Rice type, this model being easy to equalize. Model E is the most difficult to equalize, since its RMS delay reaches 250 ns and requires a training sequence making it possible to estimate the channel over a duration of close to 50 symbols. The performance here is dependent on the number of survivors S chosen. However, the choice S = 4

seems a good performance/complexity compromise for all of the channels.

The radio frequency parameters of the A model represented in Figure 5d are given in table 3 below:

TABLE 3

Coeff. Number	Delay (ns)	Average power (dB)	Rice factor K	Doppler spectrum
1	0	0.0	0	CLASS
2	10	-0.9	0	CLASS
3	20	-1.7	0	CLASS
4	30	-2.6	0	CLASS
5	40	-3.5	0	CLASS
6	50	-4.3	0	CLASS
7	60	-5.2	0	CLASS
8	70	-6.1	0	CLASS
9	80	-6.9	0	CLASS
10	90	-7.8	0	CLASS
11	110	-4.7	0	CLASS
12	140	-7.3	0	CLASS
13	170	-9.9	0	CLASS
14	200	-12.5	0	CLASS
15	240	-13.7	0	CLASS
16	290	-18.0	0	CLASS
17	340	-22.4	0	CLASS
18	390	-26.7	0	CLASS

Those of the B model are given in table 4 below:

TABLE 4

Coeff. Number	Delay (ns)	Average power (dB)	Rice factor K	Doppler spectrum
1	0	-2.6	0	CLASS
2	10	-3.0	0	CLASS
3	20	-3.5	0	CLASS
4	30	-3.9	0	CLASS
5	50	0.0	0	CLASS
6	80	-1.3	0	CLASS
7	110	-2.6	0	CLASS
8	140	-3.9	0	CLASS
9	180	-3.4	0	CLASS
10	230	-5.6	0	CLASS
11	280	-7.7	0	CLASS
12	330	-9.9	0	CLASS
13	380	-12.1	0	CLASS
14	430	-14.3	0	CLASS
15	490	-15.4	0	CLASS
16	560	-18.4	0	CLASS
17	640	-20.7	0	CLASS
18	730	-24.6	0	CLASS

Those of the C model are given in table 5:

TABLE 5

Coeff. Number	Delay (ns)	Average power (dB)	Rice factor K	Doppler spectrum
1	0	-3.3	0	CLASS
2	10	-3.6	0	CLASS
3	20	-3.9	0	CLASS
4	30	-4.2	0	CLASS
5	50	0.0	0	CLASS
6	80	-0.9	0	CLASS
7	110	-1.7	0	CLASS
8	140	-2.6	0	CLASS
9	180	-1.5	0	CLASS
10	230	-3.0	0	CLASS
11	280	-4.4	0	CLASS
12	330	-5.9	0	CLASS
13	400	-5.3	0	CLASS
14	490	-7.9	0	CLASS
15	600	-9.4	0	CLASS
16	730	-13.2	0	CLASS
17	880	-16.3	0	CLASS
18	1050	-21.2	0	CLASS

Those of the D model are given in table 6 below:

TABLE 6

Coeff. Number	Delay (ns)	Average power (dB)	Rice factor K	Doppler spectrum
1	0	0.0	10	CLASS+SPIKE
2	10	-10.0	0	CLASS
3	20	-10.3	0	CLASS
4	30	-10.6	0	CLASS
5	50	-6.4	0	CLASS
6	80	-7.2	0	CLASS
7	110	-8.1	0	CLASS
8	140	-9.0	0	CLASS
9	180	-7.9	0	CLASS
10	230	-9.4	0	CLASS
11	280	-10.8	0	CLASS
12	330	-12.3	0	CLASS
13	400	-11.7	0	CLASS
14	490	-14.3	0	CLASS
15	600	-15.8	0	CLASS
16	730	-19.6	0	CLASS
17	880	-22.7	0	CLASS
18	1050	-27.6	0	CLASS

Those of the E model are given in table 7 below:

TABLE 7

Coeff. Number	Delay (ns)	Average power (dB)	Rice factor K	Doppler spectrum
1	0	-4.9	0	CLASS
2	10	-5.1	0	CLASS
3	20	-5.2	0	CLASS
4	40	-0.8	0	CLASS
5	70	-1.3	0	CLASS
6	100	-1.9	0	CLASS
7	140	-0.3	0	CLASS
8	190	-1.2	0	CLASS
9	240	-2.1	0	CLASS
10	320	0.0	0	CLASS
11	430	-1.9	0	CLASS
12	560	-2.8	0	CLASS
13	710	-5.4	0	CLASS
14	880	-7.3	0	CLASS
15	1070	-10.6	0	CLASS
16	1280	-13.4	0	CLASS
17	1510	-17.4	0	CLASS
18	1760	-20.9	0	CLASS

CLAIMS

1. A method of decoding and of joint equalization of a digital signal protected by a code defined by a trellis, this signal being transmitted on a radio frequency channel according to a transmission with non-interleaved packets, each packet including a known sequence and a sequence of coded data, each sequence of bits $x = \{x_n\}$, from current bit x_n, subjected to the coding process defined by a trellis and to a modulation process, having a corresponding sequence of symbols $y = \{y_n\}$, from current symbol y_n, satisfying the relationship $y_n = f(x_n; x_{n-1}; \ldots; x_{n-K})$, the sequence of bits prior to the current bit $e_{n-1}(x) = \{x_{n-1}; x_{n-2}; \ldots; x_{n-K}\}$ representing the state of the coding process at the previous state n-1 and the current symbol y_n of the sequence of symbols satisfies the relationship $y_n = f(x_n, e_{n-1}(x))$, the sequence of symbols being submitted to a transverse filtering with finite impulse response, with filtering coefficients $\{h_0; h_1; \ldots; h_L\}$ representative of the radio frequency channel in order to generate a sequence of observed symbols $r = \{r_n\}$, each observed symbol r_n satisfying the relationship $r_n = z_n+b_n$ where z_n designates a current symbol at the output of the channel and b_n a residual noise affecting the latter, each current symbol at the output of the channel z_n satisfying the relationship:

$$\begin{aligned} z_n &= g\,(y_n; y_{n-1}; \ldots; y_{n-L}) \\ &= h_0 y_n + h_1 y_{n-1} + \ldots + h_L y_{n-L} \\ &= \Phi(x_n; x_{n-1}; \ldots; x_{n-L-K}) \end{aligned}$$

this method consisting in estimating each current bit x_n of the sequence of bits $x = \{x_n\}$ in the sense of the maximum likelihood by minimizing the quadratic error between observed symbol and current symbol at the channel output,

$$\varepsilon^2(x) = \sum_n |r_n - z_n|^2 = \sum_n |r_n - \phi(x_n; x_{n-1}; \ldots; x_{n-L-K})|^2,$$

characterized in that, for any current symbol at the output of the channel z_n arising from the transmission, because of multiple paths, the successive sequence of the symbols $\{y_{n-L};\ y_{n-L+1};\ y_{n-1};\ y_n\}$ arising from the coding process for the sequence of bits $x = \{x_n\}$ corresponding to successive states $e_{n-L}(x)$; $e_{n-L+1}(x)$; ...; $e_{n-1}(x)$ and finally $e_n(x)$, corresponding to branches between successive state nodes of the trellis of the code, this method moreover consisting:

- in calculating said quadratic error on the basis of the set of observed symbols and of the successive state branches of the coding process, on the basis of the branch metric of the last transition $e_{n-1}(x) \rightarrow e_n(x)$ of the coding process, according to the relationship:

$$\varepsilon^2(x) = \sum_n \left| r_n - \left\{ \sum_{k\geq 0} h_k y_{n-k} \right\} \right|^2 = \sum_n \left| r_n - h_0 y_n - \left\{ \sum_{k\geq 1} h_k y_{n-k} \right\} \right|^2$$

said branch metric being calculated by ascending the successive states at the level of each state node over a length equal to the memory of the channel;

- in inhibiting, in the course of this ascent, the process of error propagation because of the calculation of the branch metrics, by memory-storage at the level of each node i and at each instant of a number S > 1 of survivors, each survivor being defined by an accumulated metric M(i,t,k) for the node i at the instant t for the survivor of ranking k in question, k $\in$[0, ..., S-1], and by an updating of each survivor at the instant t + 1 for each node by calculation of a branch metric and selection of the S best branch metrics from among the set of possible branch metrics at the node in question;

- in determining the final survivor with the smallest metric, $M_m(0,\tau,0)$, and in reading the corresponding sequence of information bits, by ascending successive state nodes.

2. The method according to Claim 1, characterized in that it further consists:

- in determining a next-final survivor with metric $M_{m'}(0,\tau,1)$, adjacent to and immediately above the smallest metric,

- in calculating a metric offset, the absolute value in the difference in metrics between the smallest metric and the immediately higher adjacent metric, $\delta_M = |M_m - M_{m'}|$;

- in comparing this metric offset with a threshold value $\delta_M \leq S_e$, this threshold value S_e being defined on the basis of experimental results and of conditions of use;

- in rejecting the final survivor when said metric offset satisfies the comparison of being below this threshold value, which makes it possible to enhance the reliability of the method.

10/070854

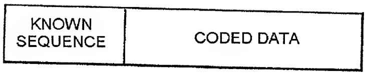


FIG.1. (PRIOR ART)

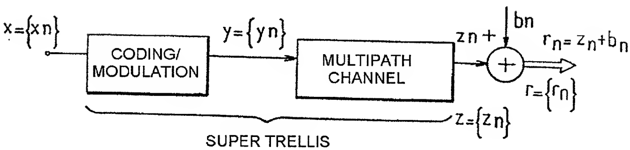


FIG.2a.

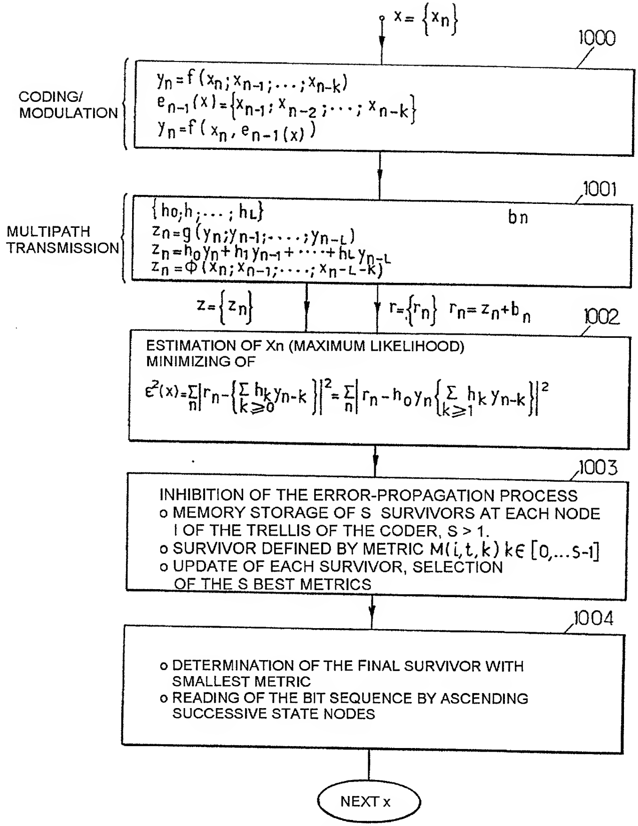
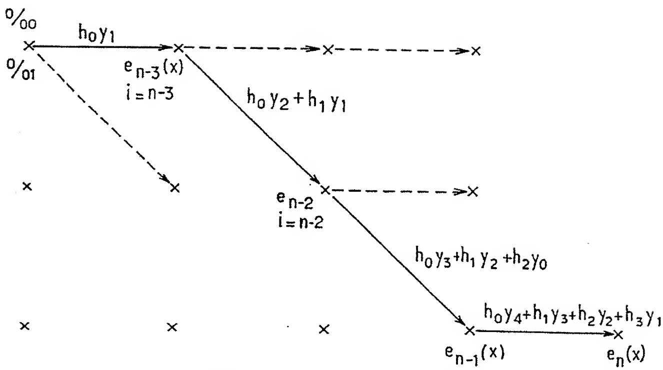
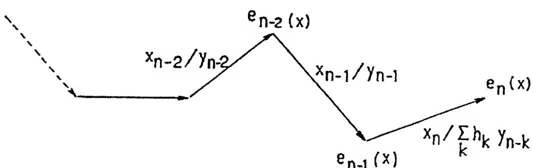

$x=\{x_n\}$
1000
CODING/ MODULATION
$y_n=f(x_n;x_{n-1};\dots;x_{n-k})$
$e_{n-1}(x)=\{x_{n-1};x_{n-2};\dots;x_{n-k}\}$
$y_n=f(x_n,e_{n-1}(x))$
1001
MULTIPATH TRANSMISSION
$\{h_0;h_1;\dots;h_L\}$
b_n
$z_n=g(y_n;y_{n-1};\dots;y_{n-L})$
$z_n=h_0y_n+h_1y_{n-1}+\dots+h_Ly_{n-L}$
$z_n=\Phi(x_n;x_{n-1};\dots;x_{n-L-k})$
$z=\{z_n\}$
$r=\{r_n\}$ $r_n=z_n+b_n$
1002
ESTIMATION OF Xn (MAXIMUM LIKELIHOOD) MINIMIZING OF
$\varepsilon^2(x)=\sum_n\left|r_n-\left\{\sum_{k\geq 0}h_ky_{n-k}\right\}\right|^2=\sum_n\left|r_n-h_0y_n\left\{\sum_{k\geq 1}h_ky_{n-k}\right\}\right|^2$
1003
INHIBITION OF THE ERROR-PROPAGATION PROCESS
o MEMORY STORAGE OF S SURVIVORS AT EACH NODE I OF THE TRELLIS OF THE CODER, S > 1.
o SURVIVOR DEFINED BY METRIC $M(i,t,k)$ $k\in[0,\dots S-1]$
o UPDATE OF EACH SURVIVOR, SELECTION OF THE S BEST METRICS
1004
o DETERMINATION OF THE FINAL SURVIVOR WITH SMALLEST METRIC
o READING OF THE BIT SEQUENCE BY ASCENDING SUCCESSIVE STATE NODES
NEXT x

FIG.2b.



0/00
$h_0 y_1$
0/01
$e_{n-3}(x)$
$i=n-3$
$h_0 y_2 + h_1 y_1$
e_{n-2}
$i=n-2$
$h_0 y_3 + h_1 y_2 + h_2 y_0$
$h_0 y_4 + h_1 y_3 + h_2 y_2 + h_3 y_1$
$e_{n-1}(x)$
$i=n-1$
$e_n(x)$
$i=n$

FIG. 3a.



$e_{n-2}(x)$
x_{n-2}/y_{n-2}
x_{n-1}/y_{n-1}
$e_n(x)$
$x_n/\sum_k h_k y_{n-k}$
$e_{n-1}(x)$

FIG. 3b.

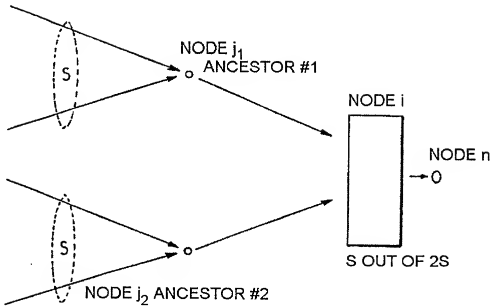

NODE j_1
ANCESTOR #1
S
NODE i
NODE n
0
S
S OUT OF 2S
NODE j_2 ANCESTOR #2

FIG.3c.

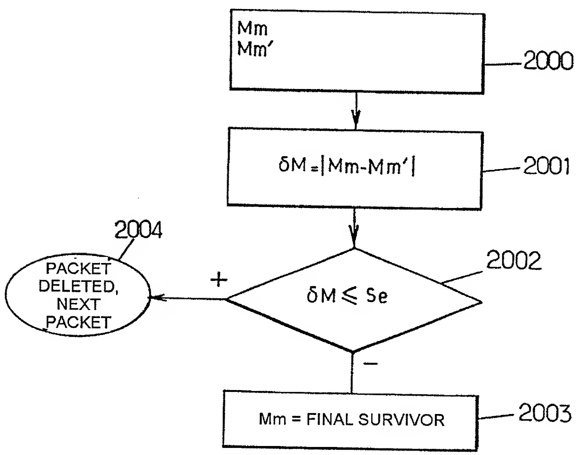

Mm
Mm′
2000
δM = |Mm-Mm′|
2001
2004
PACKET DELETED, NEXT PACKET
+
δM ≤ Se
2002
−
Mm = FINAL SURVIVOR
2003

FIG.4.

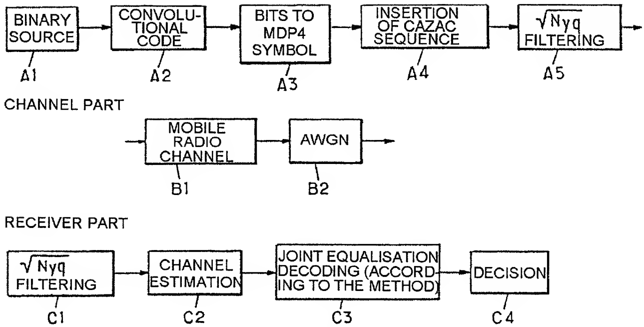

BINARY SOURCE
CONVOLU-TIONAL CODE
BITS TO MDP4 SYMBOL
INSERTION OF CAZAC SEQUENCE
√Nyq FILTERING
A1
A2
A3
A4
A5
CHANNEL PART
MOBILE RADIO CHANNEL
AWGN
B1
B2
RECEIVER PART
√Nyq FILTERING
CHANNEL ESTIMATION
JOINT EQUALISATION DECODING (ACCORDING TO THE METHOD)
DECISION
C1
C2
C3
C4

FIG.5a.

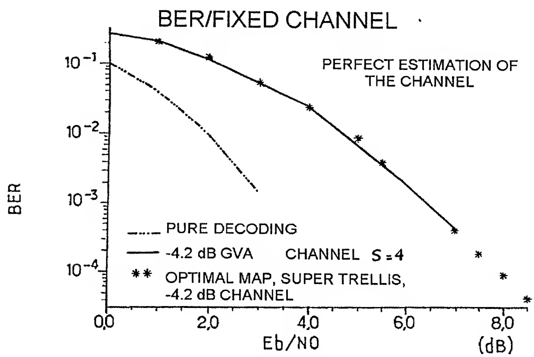

BER/FIXED CHANNEL
PERFECT ESTIMATION OF THE CHANNEL
BER
10⁻¹
10⁻²
10⁻³
10⁻⁴
PURE DECODING
-4.2 dB GVA
CHANNEL S=4
OPTIMAL MAP, SUPER TRELLIS, -4.2 dB CHANNEL
0,0
2,0
4,0
6,0
8,0
Eb/NO
(dB)

FIG.5b.

10/070054

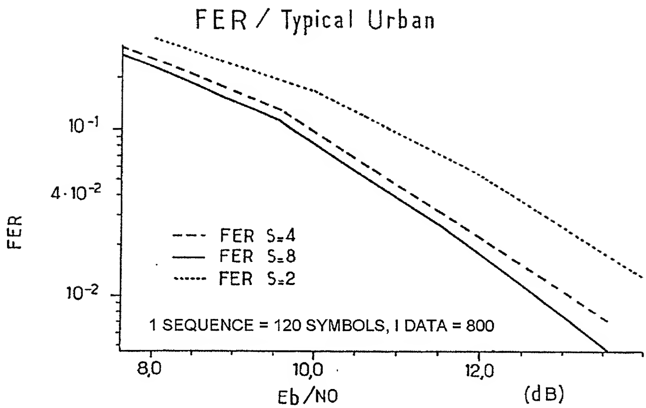


FIG. 5c.

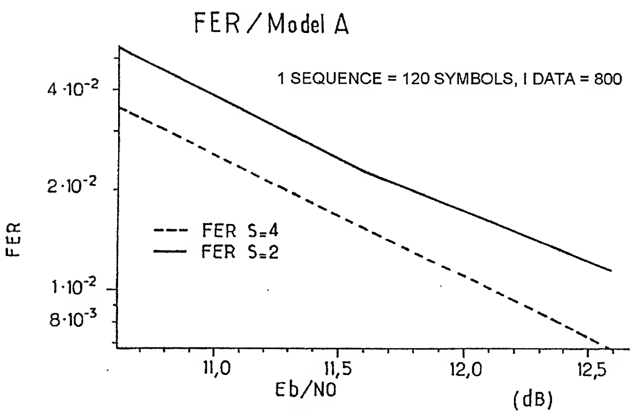


FIG. 5d.

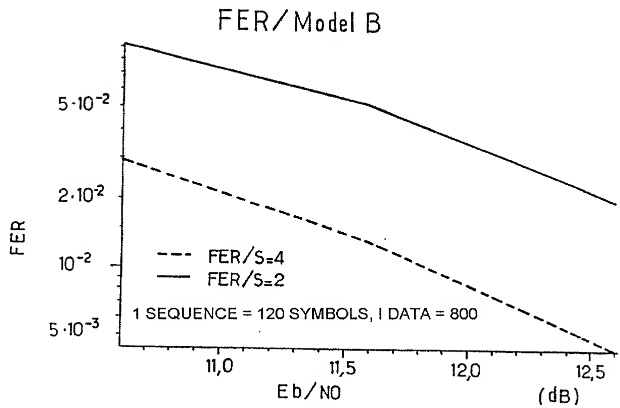

FER/Model B
5·10⁻²
2·10⁻²
10⁻²
5·10⁻³
FER
FER/S=4
FER/S=2
1 SEQUENCE = 120 SYMBOLS, I DATA = 800
11,0
11,5
12,0
12,5
Eb/NO
(dB)

FIG.5e.

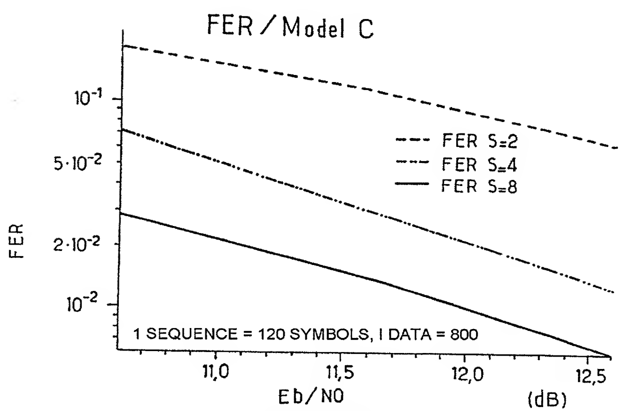

FER/Model C
10⁻¹
5·10⁻²
2·10⁻²
10⁻²
FER
FER S=2
FER S=4
FER S=8
1 SEQUENCE = 120 SYMBOLS, I DATA = 800
11,0
11,5
12,0
12,5
Eb/NO
(dB)

FIG.5f.

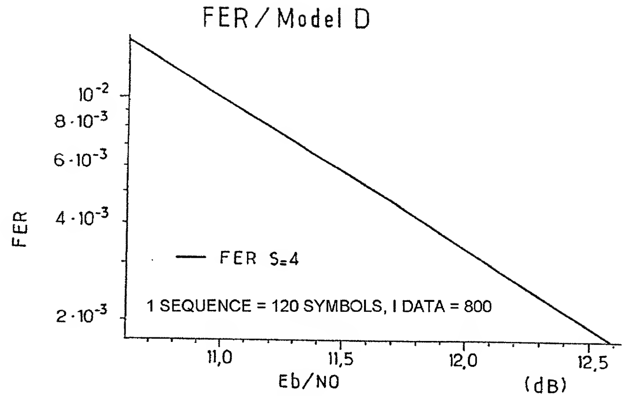

FER / Model D
FER
10^{-2}
$8 \cdot 10^{-3}$
$6 \cdot 10^{-3}$
$4 \cdot 10^{-3}$
$2 \cdot 10^{-3}$
FER S=4
1 SEQUENCE = 120 SYMBOLS, I DATA = 800
11,0
11,5
12,0
12,5
Eb/NO
(dB)

FIG. 5g.

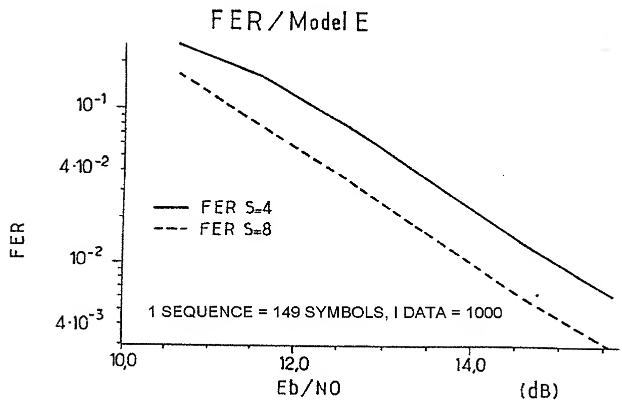

FER / Model E
FER
10^{-1}
$4 \cdot 10^{-2}$
10^{-2}
$4 \cdot 10^{-3}$
FER S=4
FER S=8
1 SEQUENCE = 149 SYMBOLS, I DATA = 1000
10,0
12,0
14,0
Eb/NO
(dB)

FIG. 5h.

"Egalisation conjointe bis"

Atty. Docket No: ______________

DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled " Method of decoding and of joint equalization of a digital signal protected by a code defined by a trellis. ,"

the specification of which (check one): ☒ is attached hereto; ☐ was filed on ______________ as Application Serial No. ______________ and was amended on ______________ (if applicable); ☐ was filed as PCT International Application No. ______________ on ______________ and was amended under Article 19 on ______________ (if applicable). I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose to the Patent and Trademark Office all information known to me to be material to patentability as defined in 37 C.F.R. §1.56.

I hereby claim foreign priority benefits under 35 U.S.C. §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

(Application Serial Number)	(Country)	(Day/Month/Year Filed)	Priority Claimed Yes	Priority Claimed No
FR 99 11411	FRANCE	13/09/1999	☒	☐
			☐	☐

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below:

(Application Serial Number)	(Day/Month/Year Filed)

I hereby claim the benefit under 35 U.S.C. §120 of any United States application(s) or PCT international application(s) designating the United States of America listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior application(s) in the manner provided by the first paragraph of 35 U.S.C. §112, I acknowledge the duty to disclose to the Office all information known to me to be material to patentability as defined in 37 C.F.R. §1.56 which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

(Application Serial Number)	(Day/Month/Year Filed)	(Status-Patented, Pending or Abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: I hereby appoint as my attorneys, with full powers of substitution and revocation, to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

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James P. Zeller (28,491)
Kevin D. Hogg (31,839)
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200

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City (Zip)	City (Zip)
State or Country	State or Country
Date :	Signature :

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City (Zip)	City (Zip)
State or Country	State or Country
Date :	Signature :